APPLICATION UNDER UNITED STATES PATENT LAWS

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Invention: PLASMA REACTOR

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<u>This is a:</u>

☐ Provisional Application

☒ Regular Utility Application

☐ Continuing Application
☐ The contents of the parent are incorporated by reference

☐ PCT National Phase Application

☐ Design Application

☐ Reissue Application

☐ Plant Application

☐ Substitute Specification
<u>Sub. Spec</u> Filed ____________
in App. No. ______/______

☐ <u>Marked up Specification re</u>
Sub. Spec. filed ____________
In App. No ______/______

SPECIFICATION

PLASMA REACTOR

[0001] This non-provisional application claims the benefit of U.S. provisional application no. 60/465,207, filed April 25, 2003, the contents of which are incorporated in their entirety herein by reference.

FIELD OF THE INVENTION

[0002] The present invention pertains to plasma processing systems and in particular to plasma reactors.

BACKGROUND OF THE INVENTION

[0003] Plasma processing systems are used in the manufacture and processing of semiconductors, integrated circuits, displays and other devices and materials, to remove material from or to deposit material on a substrate such as a semiconductor substrate. In some instances, these plasma processing systems use electrodes for providing RF energy to a plasma useful for depositing on or removing material from a substrate.

[0004] There are several different kinds of plasma processes used during wafer or substrate processing. These processes include, for example: plasma etching, plasma deposition, plasma assisted photoresist stripping and in-situ plasma chamber cleaning.

[0005] Plasma processing systems often operate with a blend of gasses which must flow through a processing chamber. A pumping system is employed to remove gasses from the processing system.

BRIEF SUMMARY OF THE INVENTION

[0006] An aspect of the present invention is to provide a plasma reactor including a vacuum chamber and a holding structure constructed and arranged to hold a chuck assembly and a plasma source assembly. The holding structure at least partially constitutes a wall of said vacuum chamber. The plasma source can be of any type, for example, a capacitively coupled plasma (CCP) source, an inductively coupled plasma (ICP) source, a transformer coupled plasma (TCP) source, an electrostatically shielded radio frequency (ESRF) plasma source, etc.

[0007] In one embodiment, the holding structure is pivotable around a pivot point relative to a wall of the vacuum chamber thus opening up to the inside of the vacuum chamber.

[0008] Another aspect of the invention is to provide a method of accessing a chuck assembly and a plasma source assembly in a plasma reactor the chuck assembly and the plasma source assembly being held by a holding structure, the method including pivoting the holding structure around a pivot axis parallel to a surface of the holding structure. The holding structure constituting at least a portion of a wall of a vacuum chamber. The method further includes opening up a volume space in the vacuum chamber and inspecting the chuck assembly and the plasma source assembly.

[0009] The pivoting of the holding structure comprises pivoting the chuck assembly and the plasma source assembly as one assembly.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] In the accompanying drawings:

[0011] FIG. 1 is a cross-sectional view of a plasma reactor, according to an embodiment of the present invention, showing a holding structure holding a capacitively coupled plasma (CCP) source assembly, a chuck assembly, an electrode impedance match network and a chuck impedance match network;

[0012] FIG. 2 is a top view of the plasma reactor according to the embodiment shown in FIG. 1;

[0013] FIG. 3 is a cross-sectional view of the plasma reactor according to an alternative embodiment of the present invention showing a pivotable holding structure including electrode and chuck assemblies relative to a wall of the plasma process chamber;

[0014] FIG. 4 is a cross-sectional view of another embodiment of the present invention showing an integrated chuck impedance match network with an electrode impedance match network;

[0015] FIG. 5 is a top view of the plasma reactor according to the embodiment shown in FIG. 4;

[0016] FIG. 6 is a cross-sectional view of a plasma reactor according to another embodiment of the present invention using an ESRF plasma source assembly;

[0017] FIG. 7 is a top view of the plasma reactor according to the embodiment shown in FIG. 6;

[0018] FIG. 8 is a cross-sectional view of the plasma reactor according to an alternative embodiment of the present invention showing a pivotable holding structure relative to a wall of the plasma process chamber;

[0019] FIG. 9 is a cross-sectional view of a plasma reactor according to another embodiment of the present invention using an inductively coupled plasma (ICP) source assembly;

[0020] FIG. 10 is a top view of the plasma reactor according to the embodiment shown in FIG. 9;

[0021] FIG. 11 is a cross-sectional view of the plasma reactor according to yet another alternative embodiment of the present invention showing a pivotable holding structure relative to a wall of the plasma process chamber; and

[0022] FIG. 12 is a cross-sectional detail of a utility via part for RF connection to chuck assembly.

DETAILED DESCRIPTION OF SEVERAL EMBODIMENTS OF THE INVENTION

[0023] Referring now to FIG. 1, a plasma reactor 10 is shown to include a plasma chamber 12 that functions as a vacuum processing chamber adapted to perform plasma etching from and/or material deposition on a workpiece (not shown). The workpiece can be, for example, a semiconductor wafer such as silicon. However, other types of substrates are also within the scope of the present invention. Chamber 12 includes sidewall(s) 14, and chamber adapter 16 for connecting vacuum pump 18 to process chamber 12. Vacuum pump 18 can be, for example, a turbo-molecular pump (TMP) configured to evacuate excess process gases from chamber 12. Vacuum pump 18 can be isolated from chamber 12 using gate valve 19.

[0024] Holding structure 20 supports both electrode assembly 24 and chuck assembly 26. The electrode assembly 24 is arranged adjacent chuck assembly 26 to form interior region 22. In one embodiment, the electrode assembly 24 is configured to form part of the holding structure 20 by helping support chuck assembly 26.

[0025] The workpiece support or chuck assembly 26 supports a workpiece while it is processed in chamber 12. In this embodiment, electrode assembly 24 is capacitively coupled to the plasma when the workpiece is being plasma processed, i.e. a capacitively coupled plasma (CCP) source assembly is used in plasma reactor 10. The plasma is formed in interior region 22. The plasma may have a plasma density (i.e., number of ions/volume, along with energy/ion) that is uniform, unless the density needs to be tailored to account for other sources of process non-uniformities or to achieve a desired process non-uniformity. In order to protect the electrode assembly 24 and other components from heat damage due to the plasma, a cooling system in fluid communication with electrode assembly 24 is preferably included for flowing a cooling fluid to and from the electrode assembly 24.

[0026] Electrode assembly 24 may be electrically connected to an RF power supply system 32 via electrode impedance match network 28. The impedance match network matches the impedance of power supply system 32 to the impedance of the electrode assembly 24 and the associated excited plasma. In this way, the power may be delivered by the RF power supply to the plasma electrode assembly 24 and the associated excited plasma with reduced reflection.

[0027] In addition, the chuck assembly 26 used to support the workpiece, substrate or wafer can also be provided with an RF power supply coupled thereto to bias the wafer. Similarly to the electrode assembly, the RF bias can be applied to wafer chuck assembly through chuck impedance match network 30. A ultility via assembly 31 (described in more detail below) is constructed and arranged to provide RF connection to chuck assembly 26. Other utilities can be connected through utility via 33 to the chuck assembly 26. Such utilities can include cooling systems and/or temperature regulation systems, for example. Insulator(s) 29 are also provided to electrically decouple the electrode assembly 24 and chuck assembly 26 and their respective impedance match networks 28 and 30 to allow onset of a plasma in region 22 between electrode assembly 24 and chuck assembly 26.

[0028] The plasma reactor 10 further includes a gas supply system 32 in pneumatic communication with plasma chamber 12 via one or more gas conduits 34 for supplying gas in a regulated manner to form the plasma. Gas supply system 32 can supply one or more gases such as chlorine, hydrogen-bromide, octafluorocyclobutane, and various other fluorocarbon compounds, and for chemical vapor deposition applications can supply one or more gases such as silane, tungsten-tetrachloride, titanium-tetrachloride, or the like.

[0029] Plasma reactor 10 may further include a workpiece handling and robotic system 36 in operative communication with chamber 12 for transporting workpieces to and from workpiece support or chuck assembly 26. The robotic system 36 is arranged in robotic chamber 37 which can be isolated from process chamber 12 by the use of slot valve 38. When the robotic system has finished transporting and depositing the wafer on the chuck assembly 26, the robotic system retracts back to robotic chamber 37 allowing the slot valve 38 to isolate process chamber 12 from robotic chamber 37.

[0030] Plasma reactor 10 may further include a main control system 50 to which RF power supply systems, gas supply system 32, vacuum system 18, and workpiece handling and robotic system 36 are electronically connected. In one embodiment, main control system 50 is a computer having a memory unit MU having both a random access memory (RAM) and a read-only memory (ROM), a central processing unit CPU, and a hard disk HD, all in electronic communication. Hard disk HD serves as a secondary computer-readable storage medium, and may be for example, a hard disk drive for storing information corresponding to instructions for controlling plasma reactor 10. The control system 50 may also include a disk drive DD, electronically connected to hard disk HD, memory unit MU and central processing unit CPU, wherein the disk drive is capable of reading and/or writing to a computer-readable medium CRM, such as a floppy disk or compact disc (CD) on which is stored information corresponding to instructions for control system 50 to control the operation of plasma reactor 10.

[0031] The chuck assembly 26 and vacuum pump 18 are centered on the same axis. The chuck assembly 26, being held by the holding structure 20 and associated utility via assembly 31, is open from all sides, providing symmetrical path to vacuum pump 18. Therefore, the gaseous environment all around the chuck assembly 26 and particularly in the plasma region 22 is pumped symmetrically by the vacuum pump 18.

[0032] An example of a pumping system that provides symmetrical exhaust of gases can be found in a co-assigned U.S. Patent Application 09/686,167 entitled "Reduced Impedance Chamber."

[0033] FIG. 2 is a top view of the plasma reactor 10 along the 2-2 line in FIG. 1. FIG. 2 shows electrode impedance match network 28 and chuck impedance match network 30. The electrode impedance match network 28 and the chuck impedance match network 30 are electrically decoupled by insulators 29 (shown in FIG. 1). For example, insulators 29 can be formed of a substantially non-conductive material such as, but not limited to, Rexolite, alumina, quartz, Teflon, and ceramics. FIG. 2 also shows a top view of robotic system 36 in operative communication with chamber 12 for transporting workpieces to and from workpiece support or chuck assembly 26 (shown in FIG. 1). The robotic system 36 is enclosed in robotic chamber 37 which can be isolated from process chamber 12 by the use of slot valve 38.

[0034] FIG. 3 is a cross-sectional view of the plasma reactor 10 according to another embodiment of the invention. This embodiment of the plasma reactor 10 is similar to the embodiment of the plasma reactor shown in FIG. 1. In this embodiment, upper holding structure 20 holds both the electrode assembly 24 as well as the chuck assembly 26. In this embodiment, the electrode assembly 24 is constructed to play the role of the upper holding structure 20 such that the electrode assembly 24 holds the chuck assembly 26 as well as other components including electrode impedance match network 28 and chuck impedance match network 30. The electrode assembly 24 and the chuck assembly 26 are spaced apart from each other to form plasma region 22.

[0035] As shown in FIG. 3, the upper holding structure 20 is pivotable around pivot point 40 relative to wall 14 of the plasma process chamber 12, allowing opening of process chamber 12. The upper holding structure 20 can also be pivotable around pivot axis 40' parallel to a surface of the holding structure 20, for opening of the process chamber 12. Since the upper holding structure 20 holds the chuck assembly 26 and the electrode assembly 24, the chuck and electrode assemblies pivot as one assembly opening up the volume space in the vacuum process chamber 12. In this way, cleaning of the process chamber can be made easier to perform. In addition, the pivoting of the upper holding structure 20 allows for easier access to chuck assembly 26 thus facilitating

servicing of the chuck assembly 26 and other components such as utilities connections (utility vias) 31 and 33.

[0036] Similarly to the embodiment shown in FIG. 1, the chuck assembly 26 being held by the holding structure 20 allows freeing the space around the opening in vacuum pump 18 and all around the chuck assembly 26. Therefore, the gaseous environment all around the chuck assembly 26 and particularly in the plasma region 22 is pumped symmetrically by the vacuum pump 18.

[0037] FIG. 4 is a cross-sectional view of another embodiment of a plasma reactor showing the chuck impedance match network 30 and the electrode impedance match network 28 integrated to form one impedance match network. This embodiment of the plasma reactor 10 is similar to the embodiment of the plasma reactor shown in FIG. 1. In this embodiment, similarly to the previous embodiments, upper holding structure 20 holds both the electrode assembly 24 as well as the chuck assembly 26. The upper holding structure 20 also holds other components including electrode impedance match network 28 and chuck impedance match network 30. The electrode assembly 24 and the chuck assembly 26 are spaced apart from each other to form plasma region 22. In this embodiment, however, the electrode impedance match network 28 and the chuck impedance match network 30 are integrated to form a single common impedance match network.

[0038] In this embodiment, the upper holding structure 20 can be made pivotable around pivot point 40 or pivot axis 40' relative to wall 14 of the plasma process chamber 12, allowing opening of process chamber 12.

[0039] Similarly to the previous embodiments, the chuck assembly 26 being held by the holding structure 20 allows freeing the space around the opening in vacuum pump 18 and all around the chuck assembly 26. Therefore, the gaseous environment all around the chuck assembly 26 and particularly in the plasma region 22 is pumped symmetrically by the vacuum pump 18.

[0040] FIG. 5 is a top view 5-5 of the plasma reactor 10 according to the embodiment shown in FIG. 4. FIG. 5 shows electrode impedance match network 28 and chuck impedance match network 30. The electrode impedance match network 28 and the chuck impedance match network 30 are integrated to form one single impedance

match network. FIG. 5 also shows a top view robotic system 36 in operative communication with chamber 12 for transporting workpieces to and from workpiece support or chuck assembly 26 (shown in FIG. 4). The robotic system 36 is enclosed in robotic chamber 37 which can be isolated from process chamber 12 by the use of slot valve 38.

[0041] FIG. 6 is a cross-sectional view of a plasma reactor 10 according to another embodiment of the present invention. This embodiment of the plasma reactor includes some of the same components of the first embodiment of plasma reactor except that in this embodiment an inductively coupled plasma (ICP) source 60 is used instead of a CCP source. Accordingly, the upper holding structure 20' is adapted to include ICP source assembly 60, ICP impedance match network 62, and ICP inject assembly 64. ICP source 60 can also include electrostatic shielding to form an electrostatically shielded radio frequency (ESRF) source. The upper holding structure 20' also holds chuck assembly 26 which is provided with its impedance match network 30. Regardless of the source of the RF energy, the plasma in the region 22 inside of the chamber 12 is excited by the RF energy that is generated by the respective RF power generators (not shown). In the ICP plasma source assembly, the gases may be injected through the gas inject assembly 64 opposite the chuck assembly 26 holding the substrate or wafer.

[0042] FIG. 7 is a top view 7-7 of the plasma reactor 10 according to the embodiment shown in FIG. 6. FIG. 7 shows ICP impedance match network 62 and chuck impedance match network 30. The ICP impedance match network 62 and the chuck impedance match network 30 are electrically decoupled by insulator 29. FIG. 7 also shows a top view robotic system 36 in operative communication with chamber 12 for transporting workpieces to and from workpiece support or chuck assembly 26 (shown in FIG. 6). The robotic system 36 is enclosed in robotic chamber 37 which can be isolated from process chamber 12 by the use of slot valve 38.

[0043] FIG. 8 is a cross-sectional view of the plasma reactor 10 according to another embodiment of the invention. This embodiment of the plasma reactor 10 is similar to the embodiment of the plasma reactor shown in FIGs. 6 and 7. In this embodiment, upper holding structure 20' holds the ICP source assembly 60, the ICP inject assembly 64, the ICP fast match assembly 62, the chuck assembly 26 and chuck fast match assembly 30. The ICP fast match assembly 62 and chuck fast match assembly

30 are electrically decoupled with insulator 29. The ICP inject assembly 64 and the chuck assembly 26 are configured to face each other and are spaced apart from each other to form plasma region 22.

[0044] As shown in FIG. 8, the upper holding structure 20 is pivotable around pivot point 40 (or pivot axis 40') relative to wall 14 of the plasma process chamber 12, allowing opening of process chamber 12. Since the upper holding structure 20' holds the ICP source 60, the ICP inject assembly 64, the ICP fast match assembly 62, the chuck assembly 26 and chuck fast match assembly 30, pivoting the upper holding structure 26 allows one to open up the volume space in the vacuum process chamber 12. In this way, similarly to the embodiment shown in FIG. 3, cleaning of the process chamber can be made easier to perform. In addition, the pivoting of the upper holding structure 20 allows easier access to chuck assembly 26 thus facilitating servicing of the chuck assembly 26 and other components such as utilities connections (utility vias) 31 and 33.

[0045] FIG. 9 is a cross-sectional view of a plasma reactor 10 according to another embodiment of the present invention. This embodiment of the plasma reactor includes some of the same components of the previously described embodiments of plasma reactor except that in this embodiment a transformer coupled plasma (TCP) source assembly 70 is used instead of a CCP or ICP plasma source assembly. Accordingly, the upper holding structure 20" is adapted to include TCP source assembly 70, and TCP impedance match network 72. The upper holding structure 20" also holds chuck assembly 26 which is provided with its chuck impedance match network 30. The RF energy in the TCP is generated via an inductive coil 74 wound on top of processing chamber 12. The inductive coil 74 can be a transformer-type or transformer coupled plasma (TCP) source or pancake/spiral coil. The coils can be wound in spiral conformation on top of the processing chamber 12. If a TCP-type coil is utilized, a dielectric window (e.g. quartz, alumina, etc.), or even a semiconducting window such as silicon, may be employed to permit the coupling of a RF field through the upper chamber plate 76 to the plasma. In the TCP source plasma source assembly, the gases may be injected through chamber plate 76 opposite the chuck assembly 26 holding the substrate or wafer. Process gases are plumbed directly into the upper chamber plate 76. Channels interconnecting a showerhead array of gas injection orifices can be formed within the upper chamber plate 76, for example.

[0046] FIG. 10 is a top viewof the plasma reactor 10 according to the embodiment shown in FIG. 9. FIG. 10 shows TCP impedance match network 72 and chuck impedance match network 30. The ICP impedance match network 72 and the chuck impedance match network 30 are electrically decoupled by insulators 29. FIG. 10 also shows a top view robotic system 36 in operative communication with chamber 12 for transporting workpieces to and from workpiece support or chuck assembly 26 (shown in FIG. 6). The robotic system 36 is enclosed in robotic chamber 37 which can be isolated from process chamber 12 by the use of slot valve 38.

[0047] FIG. 11 is a cross-sectional view of the plasma reactor 10 according another embodiment of the invention. This embodiment of the plasma reactor 10 is similar to the embodiment of the plasma reactor shown in FIG. 8. In this embodiment, upper holding structure 20" holds the TCP source assembly 70, the TCP coil 74, the TCP impedance match network 72, the chuck assembly 26 and chuck impedance match network 30. The TCP impedance match network 72 and chuck impedance match network 30 are electrically insulated with insulator 29.

[0048] As shown in FIG. 11, the upper holding structure 20" is pivotable around pivot point 40 relative to wall 14 of the plasma process chamber 12, allowing opening of process chamber 12. The upper holding structure 20" can also be pivotable around pivot axis 40' parallel to a surface of the holding structure 20", for opening of the process chamber 12. Since the upper holding structure 20" holds the TCP source assembly 70, the TCP plate 76, the TCP impedance match network 72, the chuck assembly 26 and chuck impedance match network 30, pivoting the upper holding structure 26 allows one to open up the volume space in the vacuum process chamber 12. In this way, similarly to the embodiment shown in FIG. 3 and FIG. 8, cleaning of the process chamber can be made easier to perform. In addition, the pivoting of the upper holding structure 20" allows easier access to chuck assembly 26 thus facilitating servicing of the chuck assembly 26 and other components such as utilities connections (utility vias) 31 and 33.

[0049] FIG. 12 is a cross-sectional detail of utility via 31 for RF connection to chuck assembly 26. Utility via 31 is constructed and arranged to transmit the RF power to the chuck block 27 of chuck assembly 26 through connector 80. Connector 80 electrically couples the chuck assembly 26 to the chuck impedance match network 30 through chuck impedance match network connector 82.

[0050] Since the chamber 12 is grounded, electric insulation is provided to electrically isolate the connectors 80 and 82 from the grounded elements which include the chamber-grounds 84, the utility via housing 86 and the chuck-grounds 88. The electric insulation includes insulators 90A-E. Electric insulator 90A electrically isolates connector 82 from chamber-ground 84. Similarly, electric insulator 90B electrically isolates connectors 80 and 82 from chamber grounds 84. Electric insulator 90C electrically isolates connector 80 from chamber-grounds 84, utility housing-ground 86 and chuck-grounds 88. Electric insulator 90D electrically isolates the chuck block 27 from a focus ring 85 and chuck ground 88. Finally, electric insulator 90E electrically isolates the chuck block 27 from the chuck-ground 88.

[0051] Although the holding structure is shown in the FIG.s on top of the vacuum chamber (i.e., constituting the top wall of the vacuum chamber), one of ordinary skill in the art would appreciate that the holding structure can be placed, for example, in anyone of the sidewalls or the chamber adapter. Similarly, although the holding structure is shown in the FIG.s covering the entirety of the upper opening of the vacuum chamber, a holding structure covering only a portion of an opening in the chamber is also within the scope of the present invention. The many features and advantages of the present invention are apparent from the detailed specification and thus, it is intended by the appended claims to cover all such features and advantages of the described apparatus which follow the true spirit and scope of the invention.

[0052] Furthermore, since numerous modifications and changes will readily occur to those of skill in the art, it is not desired to limit the invention to the exact construction and operation described herein. Moreover, the process and apparatus of the present invention, like related apparatus and processes used in the semiconductor arts tend to be complex in nature and are often best practiced by empirically determining the appropriate values of the operating parameters or by conducting computer simulations to arrive at a best design for a given application. Accordingly, all suitable modifications and equivalents should be considered as falling within the spirit and scope of the invention.